SCIENCE FOR GLASS PRODUCTION

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CURRENT TRENDS IN PRODUCTION OF GLASS CONTAINERS

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Contemporary development of glass container production is analyzed. The advisability of an integrated approach to equipping the process with imported and domestic machinery is demonstrated. The directions for improving the quality of glass-melting furnace designs and refractory materials used in these furnaces are identified.

The production of glass containers in Russia is a dynamically growing sector of industry. Whereas in 2002 the total volume of glass containers produced was 6.2 billion pieces, by 2007 it is expected to reach 12 billion per year. The production of glass articles consumes 7.9% of fuel, 13% of electricity, and 21% of mineral materials consumed in all sectors of industry. The major part of these resources is consumed in glass container production. At the same time, it should be admitted that the domestic glass product is not competitive on the world market. Only 30% of technological schemes used in the industry meet the up-to-date world level and 28% are outdated and cannot be modernized. The insufficiently high technological level is responsible for the backward position of this industrial sector regarding its essential engineering and economic parameters. The consumption of fuel and power in glass melting is 20 – 30% above the world level. The gap in operating efficiency is even greater, as it is 1.5 – 2 times lower in Russia. A serious problem is combatting negative effects on the environment. The level of emissions in the domestic glass industry is 2 time higher than in the leading glass companies abroad [1].

The current development of the glass container industry is characterized by intense investment activity. Large-scale financial investments are currently made not only in upgrading the existent production facilities, but also in setting up new up-to-date glass factories. The recent growth of production facilities for the first time has brought the volumes of production and consumption of glass containers to near equilibrium.

At the same time, the quality problems are becoming more evident. It can be stated that the domestic market, regretfully, experiences an acute shortage of high-quality inexpensive glass products. Elementary analysis shows that even one defective article in a lot of 100 glass containers makes it impossible to use the contemporary filling lines for drinks of capacity 36 – 60 thousand units per year. If products of such quality are used, the filling line efficiency is only about 20%. The foreign experience indicates that such machinery can be efficiently operated only using high-quality containers, permitting one defective article per 50 thousands containers. Evidence of the acuteness of the problem of glass container quality is the fact that drink manufacturers are taking the leading place among investors in the glass industry. The need to protect the business and make it competitive forces one to invest substantial funds in the construction of his own glass factories. The poor quality of glass containers is one of the reasons why polyethylene packaging is extensively used even for drinks than have been traditionally packaged in glass containers: natural mineral water, beer, etc.

The development of the glass-container sector is also affected by external factors that are beyond the scope of direct relationships between glass container manufactures and consumers. Such factors primarily include the dynamics of changes in the cost of fuel and power resources, materials, and transportation tariffs. These trends are very significant for the glass industry, where the cost of materials and resources reaches 50%. Historically an increase in production cost caused by external factors was offset by an increase in selling prices. However, this method has little promise in the current conditions. First, the prices are sufficiently close to the world prices. Second, considering that the international market is oversaturated with similar products, it is easy to imagine the future awaiting some domestic manufacturers with obsolete machines and technologies competing with powerful Western companies. Although the price aspect of

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this problems still gives a certain time reserve for modernizing the industry, the quality problem even today casts grave doubts on the future of numerous domestic glass factories.

An objective evaluation of the situation on the glass market encourages integration processes in the industry. The purpose of joining production and financial resources of the largest domestic glass companies is not just to have the possibility of actively influencing the market (distribution areas, prices for finished goods, etc.), but mainly to conduct a more aggressive technical policy directed to improving the efficiency and quality of products.

Thus, the existing market situation forces glass manufacturers to abandon an evolutionary way of development typical of this industry and to undertake projects that radically change the production technology and the economics of companies in general. As a consequence of this approach, virtually every single stage of the technological process at some glass factories has undergone fundamental upgrading. Since Western companies are considered as the principal competitors, this helps to identify a concept for the progress of the industry and to select parameters characterizing the technical efficiency of glass production. In other words, while developing a modernization program for an existing facility or a technical assignment for a new factory, one should be guided by state-of-the-art parameters achieved in the glass industry.

Construction of a modern efficient business implies making extensive use of the world practice. Using western technologies makes it possible to overcome in a short time the substantial gap between the domestic and foreign glass factories. At the same time, the tendency of using exclusively foreign experience may, first, unjustifiably increase the cost of the project and, second, may lead to rigid dependence on the state of the Western market. It should be remembered that the economic security of national manufacturers cannot be attained without development of Russian science and engineering; consequently, investments in the latter in the form of particular orders should be regarded as strategic investments in one's own business. In our opinion, a harmonious combination of domestic and foreign experience is the optimum way for the national sector of glass container production. Let us consider in more detail some key problems of the technical level of this sector.

The most significant changes in the domestic glass industry have lately happened in batch production. Despite the significant difference between the prices of non-concentrated and concentrated materials, there is a steady tendency to discontinue preparation of materials (crushing, grinding, concentration, fractionation) directly at the glass factory. The storage of all material components in enclosed containers, use of pneumatic transport for discharge and transportation of friable materials inside the production facility, as well as multistage dry aspiration systems make the contemporary batch-preparing shops environmentally safe. There are precedents of designing and constructing automated technological complexes with an output of over 600 tons of batch per day. The recent projects at all stages (from development of technical solutions to their implementation) evidence the characteristic style of the domestic engineering school [2].

The structure of the batch preparation process has been fundamentally modified and has become functionally rationalized. A substantial decrease in the number of heterogeneous operations and machinery items allows for implementing integrated automatization of the entire process. This significantly decreases the personnel and simplifies the whole structure of the glass production process. It is highly probable that batch-preparation shops in new facilities will lose their autonomy and become part of molding machine-melting-tank complexes.

Batch production can be represented by the following interrelated blocks of operations: discharge and storage of material; proportioning and mixing of batch components and transportation of batch to glass-melting furnaces; aspiration and automatic control system. This structural scheme can be adequately implemented only with extensive use of pneumatic transport systems. Pneumatic transport is known to have certain advantages over mechanical methods of transporting friable materials (conveyor belts, elevators, etc.). The principal ones are airtightness, a compact layout, a flexible configuration of transport routes, and, accordingly, the possibility of laying transport lines under constrained conditions. At the same time, experience shows that errors in calculation and design of pneumatic transport leads to excessive consumption of compressed air, premature wear of pipelines, blocking of routes, and occasionally to a stop of the technological process. The probability of additional grinding of material in transportation is high as well. The consequences of an incorrect calculation and design of pneumatic transport can be fully manifested as well in developing aspiration systems. Pneumatic transport and aspiration should be regarded as an integrated system in batch production and, consequently, the significance of calculation methods for these processes is evident.

It can be safely stated that the department "Equipment and automatization of silicate production" at the Ural State Technical University (UPI) has accumulated unique theoretical and practical experience in the development of state-of-the-art systems of pneumatic transport and aspiration [3, 4]. Practical implementation of this experience at a number of alumina and cement factories in our country has demonstrated that an adequate approach to solving the specified problems can significantly (a few times) increase the efficiency of traditional pneumatic transport systems. Of special practical interest is its new variant, namely, pneumatic transport in a dense layer, whose principle consists of installing a special aeration pipe of smaller diameter inside the transport pipeline.

Pneumatic transportation of disperse materials is implemented in steel pipes of diameter 100 – 180 mm. Its regime can be characterized by two parameters: the delivery concentration of material and the air flow velocity. The delivery concentration of material is equal to the ratio of the output to

the air flow rate. It shows the quantity of material pumped by one cubic meter of compressed air. The higher the concentration, the less air is needed for pumping the material.

The delivery concentration in traditional pneumatic transport depends on the length of the route. For a length of 500 – 700 m it is taken equal to 15 – 20 kg/m^3. Shorter routes (100 – 200 m) typically have a delivery concentration of 30 – 40 kg/m^3. For the above values of delivery concentration the air flow velocity is taken equal to 15 – 30 m/sec. If a pneumatic transport system is not optimally adjusted and has design defects, the delivery concentration decreases to 1 – 5 kg/m^3 and the air flow velocity increases to 50 – 70 m/sec. The consequences of this are increased consumption of compressed air and increased wear of the pipeline.

Of special practical significance is the use of pneumatic transport for such abrasive materials as feldspar and quartz sand. It appears optimum to pump these materials in a dense layer. In this case the delivery concentration of materials increases to 60 – 100 kg/m^3 with a simultaneous decrease in transportation velocity to 2 – 10 m/sec. Such significant decrease in the transportation velocity allows for a 25-fold decrease in the loss of head due to friction:

$$\Delta P = kv^2,$$

where k is the friction coefficient and v is the transportation velocity.

Thus, the implementation of the dense-layer condition on the average decreases the air flow rate to one-tenth. At the same time, an efficiency higher than the mechanical transport efficiency is reached. Furthermore, the wear of the pipeline and grinding of materials in transportation decrease perceptibly.

By the way of example let us consider two cases of upgrade of pneumatic transport systems intended for pumping alumina at the SUAL-UAZ JSC.

1. Pneumatic-chamber pumps at glass-melting furnace No. 5 used to operate with a delivery concentration of 5 kg/m^3. A vessel was discharged during 15 min. The compress air velocity at the end of the route was 67 m/sec. After the upgrade of the layout of air supply to the pneumatic-chamber pump and selection of an appropriate operating regime, the delivery concentration was increased from 5 to 15 kg/m^3, the air flow rate was decreased to one-third, and the time of the vessel discharge was shortened (from 15 to 5 min). Consequently, the efficiency of the air-chamber pump increased 3 times. After the reconstruction of 6 pneumatic transport lines, one K250 compressor with a rated engine power of 1600 kW was removed from service.

2. In 1999 two pneumatic dense-layer transport lines with a length of 400 m and a lift height up to 40 m were installed. Steady transportation now proceeds with a flow velocity below 2 – 3 m/sec at the beginning of the route and 15 – 20 m/sec at the end of the route. Due to the low transportation velocity, the resistance of the pipeline decreased significantly, which made it possible to raise the material concentration to 80 kg/m^3. At present dense-layer pneumatic transport lines up to 700 m long are being installed.

TABLE 1

Parameter	Traditional pneumatic transport	Dense-layer pneumatic transport
Air flow velocity, m/sec:		
at the beginning of the route	15	2
at the end of the route	60	20
Air flow rate, m^3/ton	240 – 360	35 – 52
Delivery concentration of material, kg/m^3	5.5	60.0 – 80.0

The practice shows that the development of pneumatic transport systems in a dense layer does not require substantial capital investments. At the same time, the operating cost of such systems is significantly lower than in traditional pneumatic transport. The development of effective pneumatic transport systems in a dense layer opens prospects for solving the problem of transporting glass batches to substantial distances. The comparative characteristics of traditional pneumatic transport and pneumatic transport in a dense layer are given in Table 1.

Proportioning machinery has lately advanced. The leading position in this area, in our opinion, is occupied by the Stromizmeritel’ JSC, whose engineers have been able to find their own way in research and development rather than copy the Western experience. Having started with single machinery items, this company currently offers integrated proportioning lines comparable with Western analogs. The use of multicomponent dosing units makes it possible, depending on the parameters of a particular building, to construct proportioning lines using different layout schemes: linear, block, or mixed schemes. It is noteworthy that the Stromizmeritel’ JSC offers the whole complex of works (from design to start-up and servicing) in setting up batch-preparation shops.

While appreciating their traditional high quality of design and manufacture of dosing equipment, we would like to mention another merit in the performance of this company. The company produces original and reliable automatic control systems for control of proportioning-and mixing lines and the batch-preparation shops in general. Their control systems, which outwardly seem simple and are easy for the personnel to operate, evidence a high level of engineer skill. In general, it can be stated that such essential part of glass production as batch preparation can be currently designed and implemented as a turn-key project on the basis of domestic machinery and engineering.

The technology of producing glass articles has radically changed, as rotary glass-forming machines are being replaced by highly efficient linear-sectional machines. This not only increases the labor efficiency many times but also significantly improves the product quality and decreases material consumption. The sectional principle of the machine I.S

TABLE 2

Parameter	Domestic furnaces	Foreign furnaces
Specific glass melt output, ton/($m^2 \cdot$ day)	≤ 1.8	≥ 2.5
Specific heat consumption on glass melting, kcal/kg	≥ 1500	≤ 1200
Furnace campaign, years	≤ 5	≥ 8
Glass melt production during furnace campaign, ton/m^2	≤ 3000	≥ 7000

makes it possible to provide for subsequent upgrades already at the stage of designing the machine. The domestic glass industry used the whole range of machines I.S, from 6 to 12 sections. I.S machines produced by various European companies are available on the Russian market and offer a good price – quality formula for the consumer.

The increasing competition on the market of glass containers and consolidation of business currently leads to two new trends in the industry. First, to lower the unit cost of constructing a glass-melting furnace, which costs 150 – 300 million rubles depending on engineering and refractories used, its minimal output should be 270 – 300 tons per day. Therefore, the technological scheme of melting tank – glass-forming machine shops that is now the most common (one furnace – two glass-forming machines) appears inappropriate. To speed up return on investment, the yield of glass melt from one furnace should be processed by at least three glass-forming automatic machines. Secondly, producing mass product one should pay special attention to the efficiency of glass-forming machines. It can be expected that in the near future the industry will rely on complexes consisting of I.S machines and more extensive use of three-drop feeding on eight- and ten-sectional machines. This will require glass-melting furnaces with an output above 300 – 400 tones per day.

At present melting tank – machine shops, as a rule, are equipped by imported integrated technological lines including all equipment from feeder canal to packaging. A prerequisite to a modern production line is installing equipment ensuring 100% quality control of the main parameters of glass containers. The wish of the customer to put all responsibility for the line performance on a single supplier is quite understandable. However, setting up glass-making shops using imported integrated machinery implies substantial financial investments.

To minimize costs and yet to preserve the technical efficiency of a project, it appears justifiable to import only the “hot segment” of the line, i.e., the glass melt feeder – the loader of glass articles into the annealing furnace. The feeder canal and the “cold segment “ of the line, except for quality control equipment, can be ordered from domestic producers. Feeder canals complete with an up-to-date temperature monitoring and automatic control system are produced by the AiST Company. Priority in designing equipment for hot and cold treatment of glass product surface is taken by the Tsentr-Steklo-Gaz JSC. An effective heating system and a reliable automated control system are found in annealing furnaces produced by the Steklomash Works (Orel). Conveyor belts and packaging equipment with semiautomatic and automatic operating modes produced by the Steklopak JSC satisfy all modern requirements imposed on glass production. It is relevant that the domestic machinery has got Russian certificates and is adapted to the quality and parameters of energy carriers used at the Russian glass factories.

The glass-melting furnace occupies a special place in the glass-production process. Its performance to a great extent determines not only the quantity and quality of the product, but the overall economics of the business. The competition and high costs of fuel and power resources in foreign countries have promoted the evolution of glass-melting furnaces. Their technical and service parameters lately have reached a very high level. However, despite the understanding of the role and significance of the glass-melting furnace in the production structure, it can be stated that in this area the gap between our knowledge and the level achieved in industrialized countries is, regretfully, the most evident. The averaged technical characteristics of container glass furnaces are given in Table 2.

It can be noted that the domestic practice counts some fortunate examples of the development and implementation of state-of-the art glass-melting furnace designs. However, they are rather exceptions than a steady trend in progress of the furnace industry.

To overcome this gap, in our opinion, two large problems related to the quality of furnace design and the quality of domestic refractories have to solved. The existing method for designing furnaces based on available practical experience was to a certain extent acceptable in the period of the evolutionary development of the industry. Defects revealed in operation used to be eliminated during cold repairs of furnaces, and certain innovations proposed by the sectoral research and development institutes were implemented. The best furnace designs were taken as the basis for designing new furnaces in the glass industry. Discrepancies with world analogs were not taken into account, since consumption of resources and furnace parameters were planned based on the average level reached in this sector. The transition to a real market has shut the access to innovations of the leading glass factories, and the collapse of research and development in the industry finally deprived the design departments of necessary information. This information vacuum could be filled by university researchers, who in industrial countries typically participate in solving applied scientific and engineering problems. A practical implementation of this idea implies the existence of sectoral programs with centralized funding. Undoubtedly, the coordinator of this activity should be the Steklosoyuz National United Council of Glass Industry Enterprises.

A lack of information and imperfect design methods resulted in the fact that several new container glass factories have installed an outdated type of the glass-melting furnace with lateral flame direction. The world practice indicates that the furnace design with horseshoe-shaped flame direction is the most effective for melting container glass up to 450 tons per day. Due to a smaller volume of refractory brickwork, fewer burners, batch-loaders, control sensors, and local temperature control systems, the cost of such furnace is 25 – 30% less than the cost of a furnace with lateral flame direction. Other terms being equal, the unit fuel consumption on a furnace with horseshoe-shaped flame is 10 – 15% lower than under a lateral-heating scheme. This is due to lower heat losses in radiation through inlet arch and charging pockets (3 times less) and a more extended heat-exchange zone between the combustion products and the tank surface (at least twice as much).

It should be noted that the high cost of contemporary glass-melting furnaces calls for a cardinal improvement of design methods to increase design quality and reliability. The calculation methods based on heat balances do not give a complete picture of the furnace performance and can be used only at the initial design stage. The leading foreign engineering companies use mathematical modeling in designing furnaces. This method of analysis not only allows for evaluation of the furnace geometry but provides a detailed understanding of the type of thermal load on all brickwork elements. This makes it possible to differentially select refractories for the most critical parts of the furnace and thus to lower the cost of its construction.

We believe that contemporary design is unthinkable without the use of CAD. The development of a computer-aided design system for glass-melting furnaces is a complicated scientific-engineering problem. CAD should be based on a mathematical model of the glass-melting process. The adequacy of this model to a great extent depends on correct formalization of the main glass-melting processes. It is evident that the glass-melting process at present cannot be formalized to a full extent. However, even approximated mathematical modeling of a glass-melting furnace raises by an order of magnitude the quality of the design solution.

One of the main reasons impeding the improvement of glass-melting furnaces is the low quality of some domestic refractory materials. These are primarily materials that form the basis of refractory brickwork in a furnace: glass Dinas, baddeleyite-corundum, and periclase [5]. The quality problems of these materials have been growing for a long time and were due to two obvious reasons: the monopoly of manufacturers and the shortage of the product. Today, when refractory manufacturers confront the real threat of losing the glass market, they are forced to make efforts to improve the quality of their products. The quality of refractories can be improved provided three interrelated problems are solved:

– bringing regulatory documentation for refractories in compliance with the standards used by the world leaders in refractory manufacture;

– revising the attitude toward source materials used in the production of refractories;

– solving a set of logistic and technical problems to ensure reliable quality of refractories.

The positive achievements of domestic furnace manufacturers include the development and production of integrated automated control systems for glass-melting furnaces and relevant ancillary equipment. A number of Russian companies are currently working in this sphere, where the AiST Company, in our opinion, is the most successful.

To conclude, it should be noted that the positive and negative trends in the glass container industry considered above do not exhaust the total range of current problems in this sector of industry.

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